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T.R.E. MEMORANDUM

No. 274

THE ADJUSTMENT OF THE VALUE OF PRINTED WIRING RESISTORS

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THE ADJUSTMENT OF THE VALUE OF PRINTED WIRING RESISTORS.

1. SUMMARY

Methods of adjusting the value of flat thin film deposited resistors for printed circuits are described and the range of adjustment for some of these methods is illustrated by charts.

2. INTRODUCTION

In conventional resistor manufacture, each resistor is grouped accordingly to a tolerance on the nominal value. This selection is carried out either after manufacture, in the case of the solid rod types, or by adjustment by calibration in the spiralled film types. The printed wiring resistor differs in that it must be designed so that it is within the required tolerance when deposited or so that its resistance balue can be easily adjusted when in position.

Three techniques for the deposition of printed resistors and the appropriate methods of calibration or adjustment are described in the following sections of this memorandum.

1. Adjustment of Aspect Ratio resistors by Fractional Electrodes.

2. Adjustment of Fixed Area resistors by overprinting or processing.

3. Adjustment of Fixed area resistors by engraving a meander.

3. ADJUSTMENT OF ASPECT RATIO RESISTORS BY FRACTIONAL ELECTRODES

The Aspect Ratio resistor technique has been described in T.R.E. Technical Note No.43 "Aspect Ratio Resistors for Printed and deposited circuit techniques". The method is based on the provision of a uniform resistance film of a known value of ohms per square. The ratio of the adjacent sides of a rectangle provides a multiplying or dividing factor to give a wide resistance range from the one value of ohms per square. With a ten to one aspect ratio, for instance, a hundred to one resistance range can be covered, i.e. one tenth to ten times the unit square value. The aspect ratio resistors are intended to be within the required tolerance after the deposition of the electrodes but the resistance value can be increased by the use of Fractional Electrodes as described in the Technical Note previously mentioned. The range of adjustment is quite wide but of course it can only increase the initial value, the resistor should therefore be designed to the lower tolerance limit. The r nge of adjustment is shown in Figures 1, 2 and 3.

It will be seen that even with high aspect ratios a fair adjustment on the tolerance is possible. In the case of the basic ohms per square the resistance value is obtained from the formula $R = kC$ where R is the required value, C is the value of the ohms per square and k is the multiplying factor obtained from the curves on Figure 1. Similarly with the high aspect ratios for resistors with electrodes on the short sides, the value can be determined from the curves on Figure 2. The adjustment of the resistors with electrodes on the long sides is covered in Figure 3. This diagram shows the percentage increase in resistance when the end square of the resistor has fractional electrodes. The percentage increase depends on the number of squares in parallel.

Examples

The required value of a resistor is 50K and the tolerance is 5%, the value of the deposited resistor formed from 100K per square sheet, is 40K, i.e. on the lower tolerance of 20%. The ratio of the sides is 2 : 1 on the long sides. It will be seen from Figure 3 that the required value will be obtained if the electrodes are shortened by 0.2 of the length of the end square, or by 10% of the present length.

The same nominal value could have been made from 10K per square material and in that case the aspect ratio would have been 5.1 with electrodes on the short sides. In this case, if the deposited value was 40K the electrodes would have to be shortened by about 65% to have an increase in resistance value of 25% as shown in Figure 2.

4. ADJUSTMENT OF FIXED AREA RESISTORS BY OVERPRINTING OR PROCESSING

This method has been widely used as a natural development of the conventional resistor. The resistor is deposited in a uniform rectangle and the value required obtained by varying the specific resistance of the material and the thickness of the deposit. The adjustment is obtained by printing successive layers or by heat and pressure processing. The usual procedure is to spray or silk screen the resistors through a mask although it is also possible to print a predetermined thickness of ink by roller or capillary methods. With experience, the required value can be deposited without critical adjustment.

There are various advantages in having standard sizes for flat film printed resistors. The principal advantage is that equipment designers can lay out the circuit without the more complex wiring necessitated by the aspect ratio resistors. Another advantage is that conventional resistors can be inserted in order to try out the circuit layout or to replace unserviceable resistors. To reduce the number of resistor inks required it is suggested, that some control be obtained by a small change in aspect ratio, i.e. by reducing the width of resistor. With a known ohms per square, aspect ratios of say five to one up to ten to one can be used. This gives us an initial two to one range and a uniform film of thickness t to 5t can be printed. A ten to one range from a known resistance film can thus be obtained. To cover 100 ohms to 1 megohm a resistance range of 10,000 to one is required. It is evident that to cover the resistance range by overprinting with the parameters outlined above, then four different values of ohms per square will be required to cover the range, through each decade. These values will be 100, 1000, 10,000 and 100,000 ohms. With constant film thickness fourteen values would be required 100, 200, 400, 800, 1600, 3200, 6000, 12500, 25000, 50,000, 100,000, 200,000, 400,000 and 800,000 ohms. The adjustment to over-printed resistors is difficult since the resistor mix needs to be cured after each additional film before the new value can be measured. The adjustment by further heat and pressure suffers from a similar disadvantage in that the resistor has to recover after processing.

5. ADJUSTMENT OF FIXED AREA RESISTORS BY ENGRAVING A MEANDER

The first requirement of a printed resistor is that it should be simple to deposit and easy to calibrate. To achieve these objects it is necessary to keep the number of engraved lines to a minimum. Figure 4 RTR11/6330 shows the increase in value gained by one system of engraved lines, using a two to one aspect ratio but with the electrodes arranged to assist the calibration. Diagram (a) shows the value of ohms per square for a convenient shape for this method. In figure (b) one electrode has been removed and the other split in the centre. It is found by experiment that the resistance value between the electrodes for this shape is now equivalent to that of a square with electrodes along opposite side. Diagram (c) shows the basic resistor element before the meander is engraved. It will be seen that the meander can be divided into a number of squares in series. At the turnover point the two square have adjacent electrodes as in diagram (c). The resistance value of each of these squares is thus 0.5C. In the example shown completed in Diagram (g) there are 18 normal square in series and 14 squares whose value equals 0.5C. The total value thus becomes 25C. For comparison a normal aspect ratio resistor is shown in diagram (h) and it will be seen that since all the squares $\frac{\ell}{x}$ by $\frac{\ell}{x}$ are equal to C then the same area provides a gain of 32 compared with 25 for the equivalent meander bu the electrodes present a difficult problem. The value of any meander resistor can be calculated from the known value of ohms per square for the film by letting the length of one side equal ℓ and the other side by ℓy. If the width of the electrodes is $\frac{\ell}{x}$ then

$$R = (x^2y - xy + 1)\,C.$$

This assumes that the gap (g) is a small fraction of $\frac{\ell}{x}$. The aspect ratio resistor as shown in diagram (h) can be deposited as a standard rectangle and engraved to within a coarse tolerance and finally calibrated to within close limits with one engraving head on one line only. The voltage stress across the gap depends on the width of the gap and the number of lines engraved.

To cover the resistance range of 100 ohms to 1 megohm with as few changes of mix as possible, a 25 to one gain factor at least would be advisable.

With the electrode ratios of two to one as shown in Figure 4 the range of 350 ohms to 6 megohms can be covered in five mixes as tabulated below:-

Ohms per square.	Minimum Value (ohms)	Maximum value (ohms)
100	350	2,500
700	2,500	17,500
5,000	17,500	125,000
35,700	125,000	892,500
250,000	875,000	6,250,000

Values below 350 ohms can be obtained by increasing the electrode lengths, that is, decreasing the aspect ratio.

The adjustment or calibration of the resistors would be carried out to the standard rectangles after curing the resistance mixutre and sealing against moisture. The resistor layout should be so arranged that the engraving can be carried out on two or three resistors simultaneously.

6. CONTINUOUS SPIRALLING ON FLAT PLATES

Figure 5a shows a form of meander that should prove useful in automatic circuit making machines. The resistance material is deposited over the parallelogram including the sloping lines coming alternately from each side. These sloping lines are the diagonals of successive rectangles whose short sides are the pitch of the spiral. If a line at right angles to the long sides moves at a constant rate over the resistor, it will intersect these diagonal lines continuously. The line at right angles could be the edge of a grinding wheel in contact with the sloping lines which would be raised above the general level of the resistor area. If the resistance film is ground off the top edge of these lines a continuous increase in resistance value will take place similar to the effect of spiralling a cylindrical resistor. The intersecting straight line could alternatively be the path of a point such as a rotary grinding head controlled by a cam, as shown in the lower half of the figure, to position the start of alternate lines and to move the grinding element at a constant rate across the resistor. The radial cam faces cause the grinding element to return rapidly and at the same time the element must be lifted clear of the resistor. The same lifting mechanism, an energised solenoid can be used in the output of a bridge circuit to stop the grinding when the required resistance value has been reached.

7. CONCLUSION

Where variations of deposited resistor value up to about 20% can be tolerated the Aspect ratio method can be used and on a few resistances in any given circuit, the method of Fractional Electrodes can be used to adjust the value within a closer tolerance. Where a number of close tolerance resistors in a circuit are required, the engraved meander system would facilitate automatic methods of adjustment.

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Figure 1.	Multiplying Factor for fractional electrodes.	RTR 11/6325
Figure 2.	Resistor adjustment by fractional electrodes.	RTR 11/6324
Figure 3.	Percentage increase due to fractional electrodes on long side of Resistors.	RTR 11/6329
Figure 4.	Increase in resistance by a meander.	RTR 11/6330
Figure 5.	Spiralling flat plate film resistors.	RTR 11/6334

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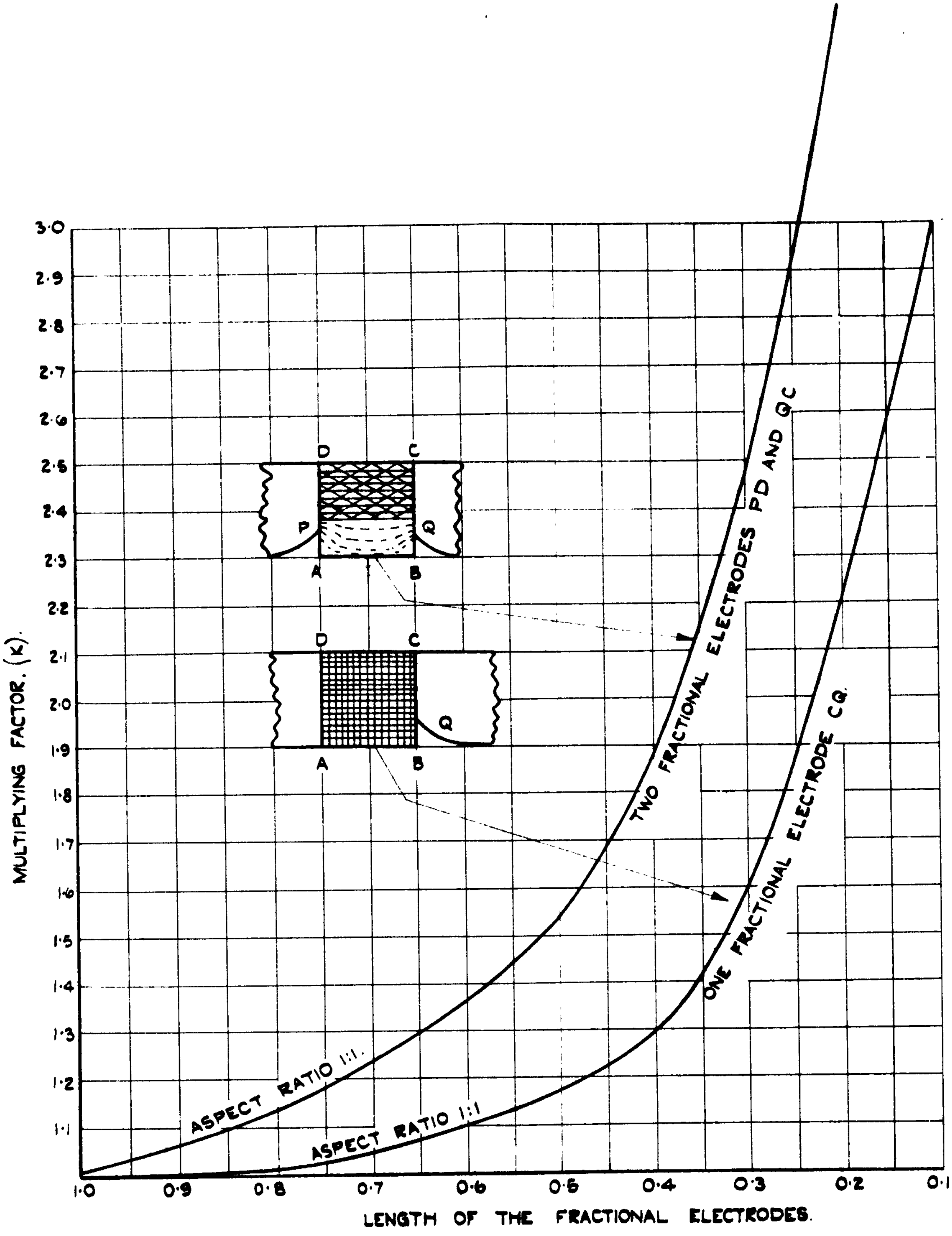

FIG. 1.
MULTIPLYING FACTOR FOR FRACTIONAL ELECTRODES.

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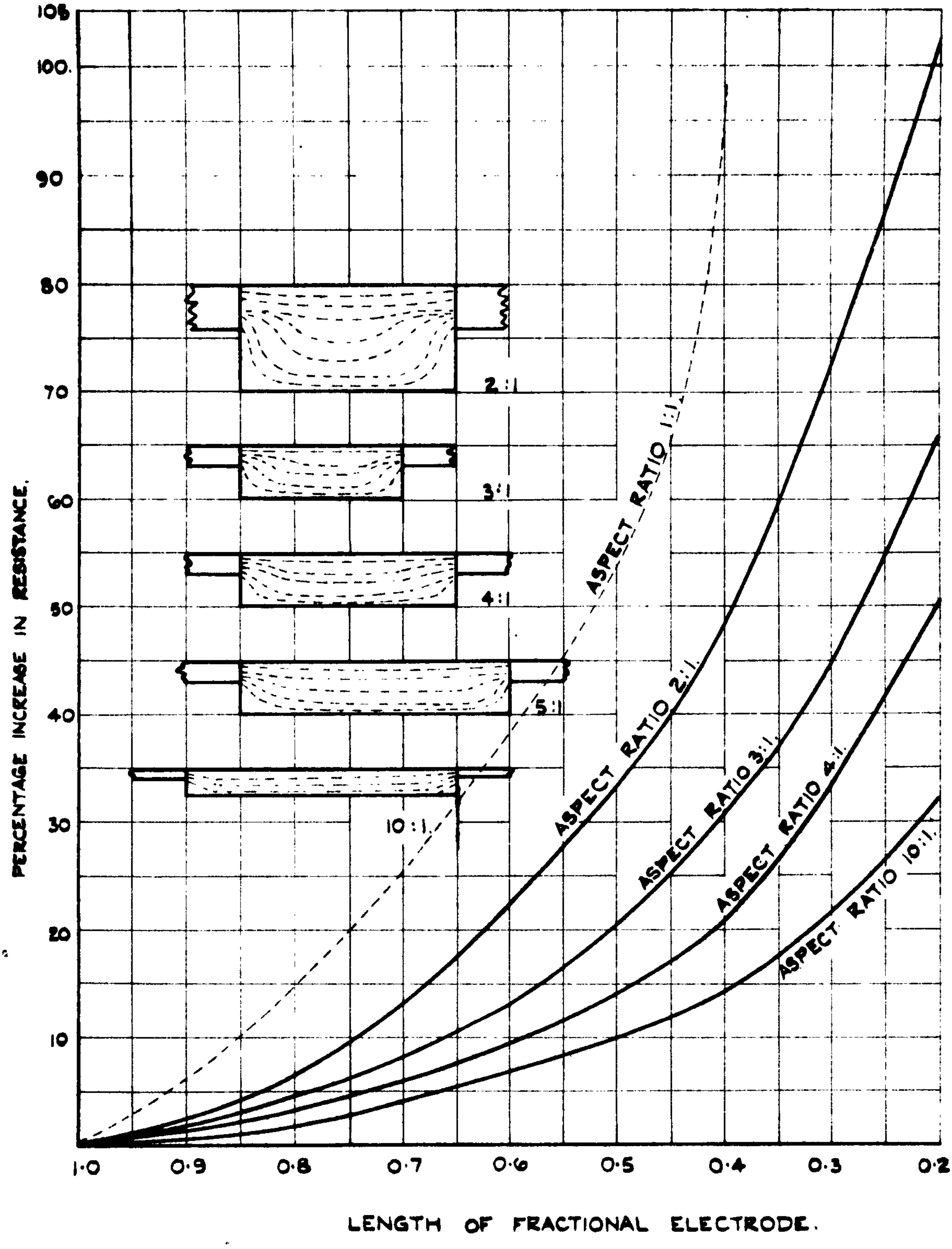

FIG. 2.

RESISTOR ADJUSTMENT BY FRACTIONAL ELECTRODES.

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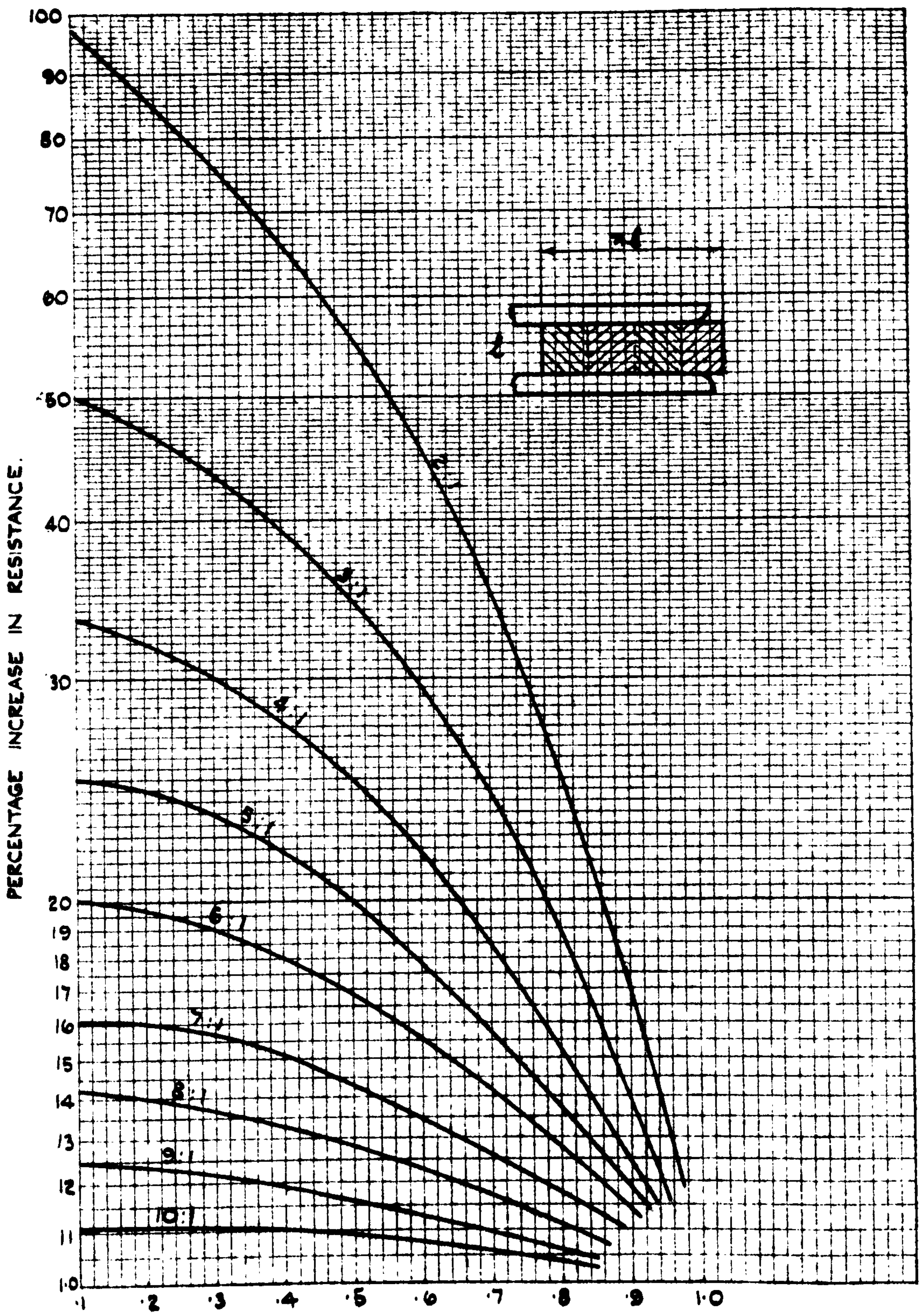

FRACTIONAL LENGTH OF ELECTRODE ALONG ONE END SQUARE ($\ell \times \ell$).

FIG. 3
PERCENTAGE INCREASE IN RESISTANCE DUE TO FRACTIONAL ELECTRODE ON LONG SIDE OF RESISTORS.

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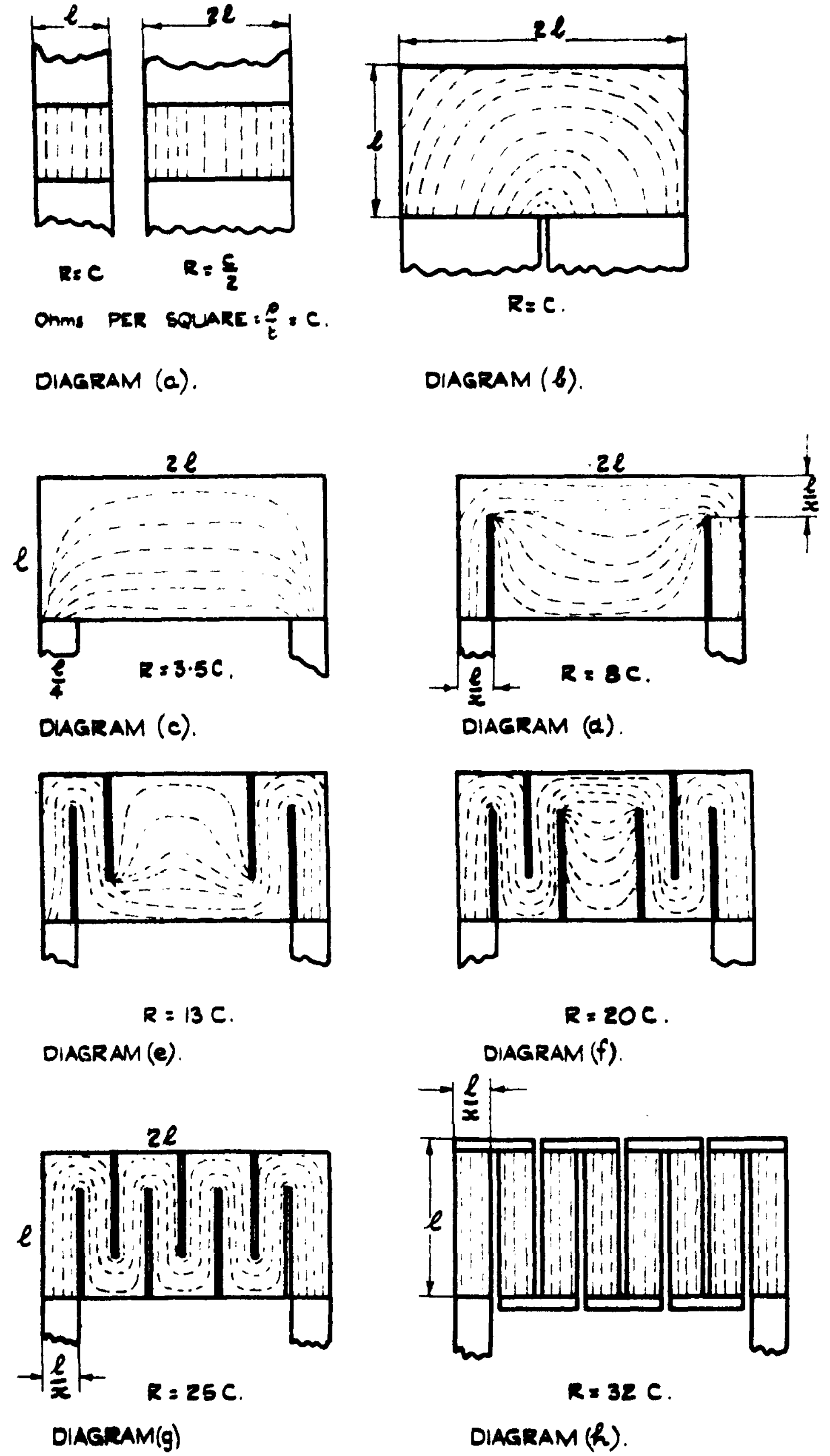

FIG. 4.

INCREASE IN RESISTANCE VALUE BY A MEANDER.

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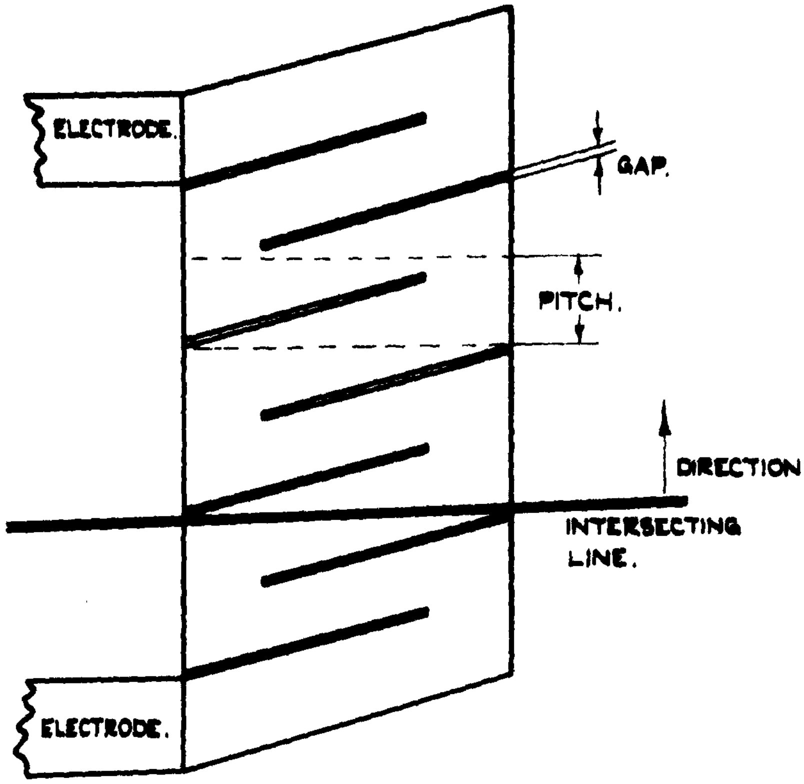

FIG. 5 (a). MEANDER FOR AUTOMATIC CONTINUOUS SPIRALLING.

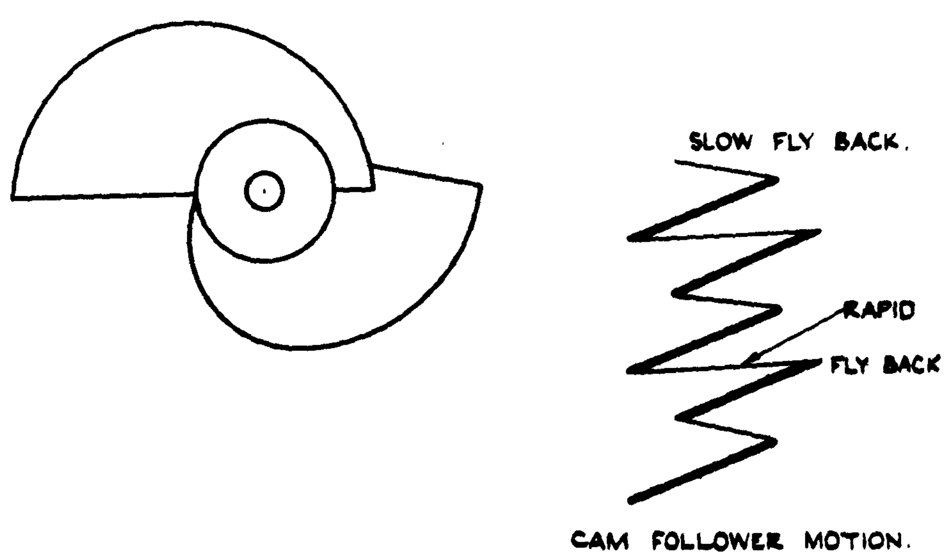

FIG. 5. (b). CAM FOR AUTOMATIC ENGRAVING HEAD.

FIG. 5.

SPIRALLING FLAT PLATE FILM RESISTORS.

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